Fermi National Accelerator Laboratory

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CDF and D0

W $\rightarrow \tau\nu$ at the Tevatron

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We present results from the CDF and DØ detectors on the production of W-bosons decaying to $\tau\nu_\tau$ at the FNAL Tevatron from data taken between 1992 and 1996. From CDF comes the first observation of W charge asymmetry in $W \to \tau\nu$ final states, and from DØ a new measurement of g_τ^W/g_e^W, 1.003 ± 0.032.

1. Introduction

In this report we present recent studies of W+jets production, with $W \to \tau\nu$, produced at the CDF and DØ detectors.

There are two compelling reasons to study $W \to \tau\nu$ events at the Tevatron. One is to provide a relatively clean sample of τ-leptons, and thus an opportunity to study the detector response to τ's. The detection of τ's at the Tevatron is considerably more difficult than of e's or μ's, and relies mainly on identifying τ hadronic decays. The main characteristics of such decays are narrow jets with low track-multiplicity. It is not easy to differentiate such jets from the much more commonly produced quark and gluon jets. Final states with τ's may be of great importance in Higgs and SUSY searches, and this fact provides a great incentive to improve the identification of τ's.

The other compelling reason is that a measurement of $W \to \tau\nu$ production, compared to measurements of $W \to e\nu$ and $W \to \mu\nu$, can be used to test lepton universality, a fundamental concept in the Standard Model. DØ reports a new and more accurate measurement of g_τ^W/g_e^W, while CDF observes for the first time W charge asymmetry in $W \to \tau\nu$, consistent with that observed in $W \to e\nu$ and $W \to \mu\nu$. Details of the CDF and DØ detectors can be found in [1] and [2] and will not be described here. However, it is worth pointing out that the central tracking region in DØ has no magnetic field (unlike CDF), so τ identification in DØ relies mostly on information from the finely segmented calorimeter. In contrast CDF relies heavily on tracking information.

2. Results from CDF

CDF has already published a measurement $g_\tau^W/g_e^W = 0.97 \pm 0.07$ based on an integrated luminosity $\int \mathcal{L}dt = 4.1\ pb^{-1}$ accumulated during 1988-1989. The sample consisted of 284 candidates with an estimated background of 101 events, see [3] for details. In 1993-1994, 65K τ-triggers were taken with $\int \mathcal{L}dt$=15.5 pb^{-1}. The trigger requirements were:

- $\not{E}_T$ >20 GeV
- τ trigger cluster $|\eta| < 1.1$
  - Charged track $P_T > 4.8$ GeV/c
  - track matched to calorimeter trigger cluster with $E_T > 10$ GeV and
  - hadronic energy/em energy>0.125 and
  - number of calorimeter towers $\leq$2 towers have $\Delta\phi$ =15° and $\Delta\eta = 0.2$.

Most of the events collected with this trigger are from standard QCD jet production. To reduce the background significantly a complicated set of offline selection cuts had to be applied:

- seed track $P_T > 5$ GeV/c within 10° of calorimeter cluster
- additional tracks with $P_T > 1$ GeV/c included in cluster if within 30° of seed track.

- $\not\!\!E_T$ >25 GeV for $\not\!\!E_T$ trigger, $\not\!\!E_T$ >20 GeV for τ-trigger
- τ cluster $E_T(\tau) > 15$ GeV
- No clusters with E_T >10 GeV other than τ
- No clusters with E_T >5 GeV for $\Delta\phi > 150°$ from τ
- No events satisfying electron or muon selection cuts.
- Track isolation (isolated if no other track with $P_T > 1$ GeV/c in annulus 10° - 30°).

After all offline selection cuts, there were 625 τ candidates. Non-isolated events are used as a background control sample. The purity of the candidate sample can be judged by the charged track multiplicity distribution shown in Fig. 1. For QCD jets, one expects a uniform charged-track multiplicity distribution between 1 and 5 while for τ one expects most of the events to have a multiplicity of 1 or 3. Furthermore, the ratio of events with 1 charged track to those with 3 charged tracks can be predicted from the τ branching ratios. The event distributions were used to obtain the fractions of signal and background, where the signal is modeled by Monte Carlo, and the background shape by data that is enriched in background. Figure 2 shows the p_T distribution for events with different charged track multiplicity, and 3 shows the energy distribution of charged tracks for different charged track multiplicity. The figures demonstrate that the data is well reproduced by a mixture of signal and background (with a signal of ≈ 400 events).

After fitting for the amount of signal as function of η separately for each charge, one can plot the charge asymmetry, $(N_+ - N_-)/(N_+ + N_-)$ where $N_{-(+)}$ is number of τ's with - (+) charge, folded about $\eta = 0$ as function of $|\eta|$, shown in Fig. 4. There is clear evidence for a charge asymmetry in $W \rightarrow \tau\nu$ events, consistent with that observed in other leptonic channels [4].

3. Results from DØ

The results in this section were shown at ICHEP98 [5]. In the period 1992-1996 DØ ac-

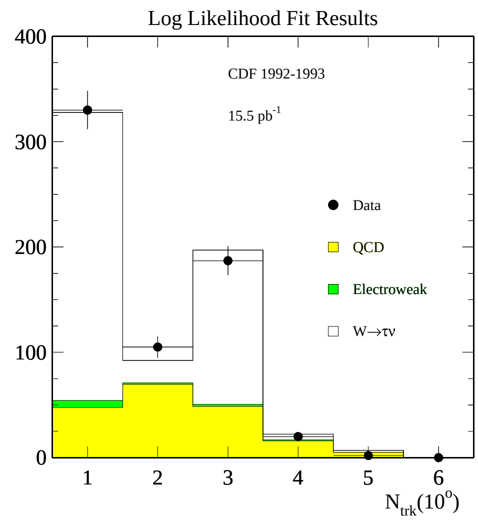

Figure 1. Charged track multiplicity distribution in τ candidates (CDF).

cumulated $\int \mathcal{L}dt = 16.8$ pb^{-1} with a special (τ) trigger designed to select $W \rightarrow \tau\nu$ events:

- Single interaction event (determined by TOF detector).
- $\not\!\!E_T$ >15 GeV
- $0.05 < EMF < 0.95$ (EMF = electromagnetic energy fraction)
- leading narrow jet $E_T > 20$ GeV, $|\eta| < 0.9$
- No other jet with $E_T > 15$ GeV within 40° of the opposite direction of the leading jet or within 30° of the $\not\!\!E_T$ direction.

A less restrictive (τ-bckg) trigger was also used to get a background control sample

- Single interaction event
- leading jet $E_T > 20$ GeV
- $0.05 < EMF < 0.95$

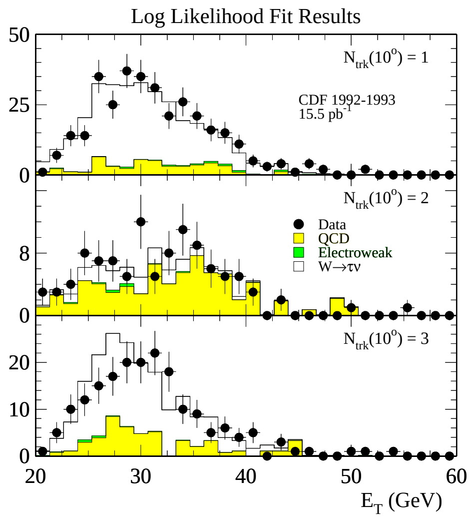

Figure 2. p_T distribution of τ candidates with 1 ,2 ,and 3 charged tracks (CDF).

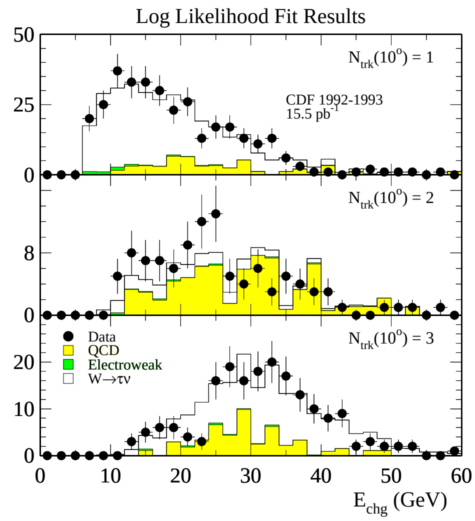

Figure 3. Energy distribution of charged tracks in τ candidates with 1, 2, and 3 charged tracks (CDF).

Events satisfying the τ trigger have further selection criteria offline to reduce the substantial background from standard QCD jets:

- $|Z - vertex|$ <60 cm
- no good electrons or muons
- τ-jet $25 < E_T < 60$ GeV, $|\eta| < 0.9$
- τ-jet width $\mathcal{W}$ <0.25 (see below)
- $\not{E}_T$ >25 GeV
- no jet with $E_T > 8$ GeV within 30° of $\not{E}_T$ direction
- no jet with $E_T > 8$ GeV with 140° - 220° of τ
- no jet with $E_T > 15$ GeV
- τ-jet profile $\mathcal{P}$ >0.55 (see below)

After all cuts, there remains a sample of 1202 events. Fig. 5a) shows the τ-jet E_T distribution for these events, and Fig. 5b) the transverse mass (m_T) calculated using the τ-jet and $\not{E}_T$. These distributions are compared to those from a data based Monte Carlo to be described shortly. The first 4 criteria above were also applied to events satisfying the τ-bckg trigger to get a background control sample. The main separation between τ-like jets and QCD jets is obtained using the jet shape variables width ($\mathcal{W}$) and profile ($\mathcal{P}$) which exploit the fine calorimeter segmentation and are defined as follows:

$$\mathcal{W} = \sqrt{\sum_{i=1}^{n} \frac{(\phi_i - \phi)^2 E_T^i}{E_T^{jet}} + \sum_{i=1}^{n} \frac{(\eta_i - \eta)^2 E_T^i}{E_T^{jet}}} \qquad (1)$$

where $i = 1 \ldots n$ indicates the calorimeter $\eta - \phi$ tower number, the sum is over all towers in the jet, and E_T^{jet} is the total E_T of the jet.

$$\mathcal{P} = \frac{E_{T1} + E_{T2}}{E_T^{jet}} \qquad (2)$$

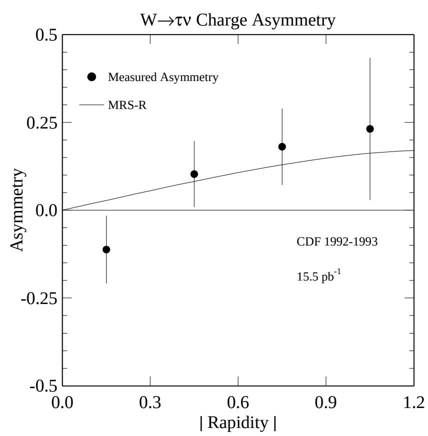

Figure 4. W charge asymmetry as function of $|\eta|$ (CDF).

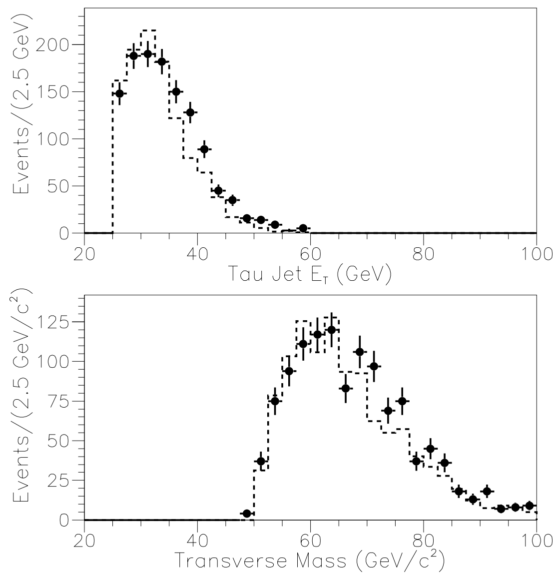

Figure 5. p_T and m_T distributions of τ candidates. The points are the data, the histograms prediction from DBMC (DØ).

where E_{T1} and E_{T2} are the E_T of the two leading towers within the jet.

The τ lepton identification is quite sensitive to noise in the calorimeter and to the underlying event. To model the signal closely a data based Monte Carlo (DBMC) was developed based on actual $W \to e\nu$ data. The procedure was to use $W \to e\nu$ events, generate a τ with the same kinematics as the electron, let the τ decay hadronically and replace all the data associated with the electron with simulated detector data from the generated τ decay. The τ decays were generated with ISAJET [7], and the detector simulation was performed using the GEANT-based [6] DØ simulation program. This procedure should reproduce the distribution of events expected from $W \to \tau\nu$, with the main shortcoming being that the statistics is limited to the actual number $W \to e\nu$ events collected during the run in the same fiducial volume as the $W \to \tau\nu$ events, containing only a single interaction per crossing ($\approx$ 10,000).

The dominant background in the $W \to \tau\nu$ final sample comes from QCD events in which the jets fluctuate to produce sufficient $\not\!\!E_T$, and one of the jets mimics a τ hadronic decay. This background can be estimated using the $\mathcal{P}$ distribution of the control sample. As shown in Figs. 6b) and c) the $\mathcal{P}$ distribution is significantly different for signal and background. There are practically no signal events with $\mathcal{P} < 0.35$, while only a small fraction of the QCD background have $\mathcal{P} > 0.55$. Using the number of events in the data with $\mathcal{P} < 0.35$, Fig. 6a), the amount of QCD background for $\mathcal{P} > 0.55$ can be estimated by relying on the distribution in Fig. 6b). It is worth noting that the shape of the $\mathcal{P}$ distribution for $\mathcal{P} < 0.35$ in the data matches quite well that expected from QCD background. This method gives a QCD background of 106 ± 7 (stat) ± 5 (sys). Another significant source of background corresponds to events with significant noise in one calorimeter cell, they produce events with τ-like jets and $\not\!\!E_T$. This background is estimated by a similar method, but instead of $\mathcal{P}$ the variable used is $\Delta\phi$, the angle between the closest track to the calorimeter cluster and the τ jet. The background has no dependence on $\Delta\phi$, while for the signal it is sharply peaked. This method esti-

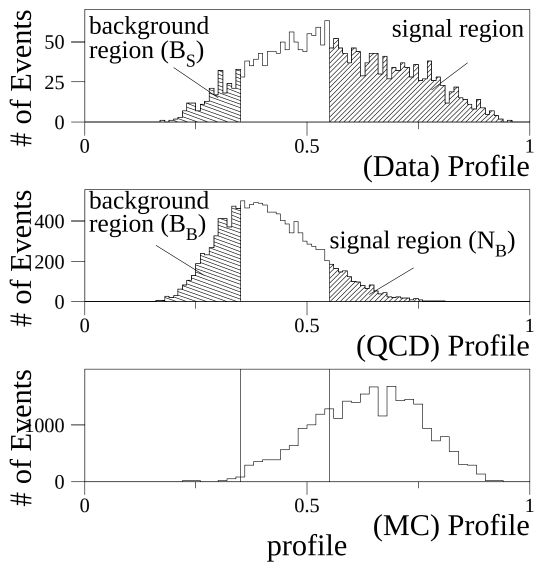

Figure 6. Profile ($\mathcal{P}$) distributions: a) τ candidates, b) QCD background c) DBMC (DØ).

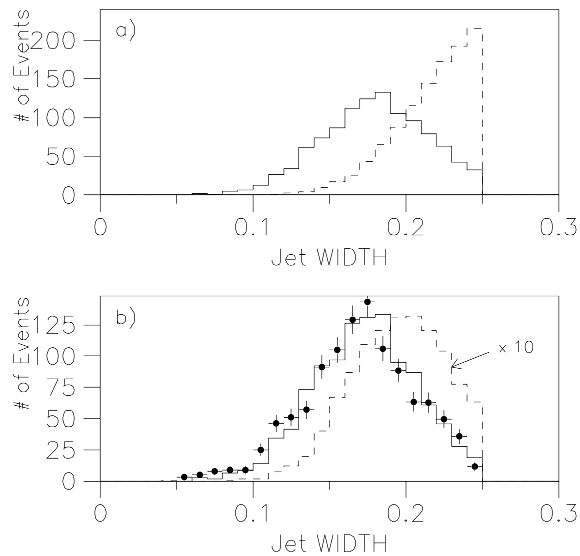

Figure 7. Jet width ($\mathcal{W}$) distributions a) no $\mathcal{P}$ cut, b) after $\mathcal{P} > 0.55$ cut. Points are background subtracted data, solid histograms are DBMC, and dashed histograms QCD (DØ).

mates the background from calorimeter noise to be 81 ± 14. Finally, there is a non-negligible background from $Z \to \tau\tau$ events, which is estimated using the ISAJET Monte Carlo to be 32 ± 5 events, and a very small background (3 ± 1 events) from $W \to e\nu$ events with the electron misidentified as a τ. The jet width distributions before and after profile cuts (background subtracted) are shown in Figs. 7a) and b), and illustrate that the data are well reproduced by the models for background and signal.

The acceptance for $W \to \tau\nu$ events, A, determined by applying geometric and kinematic cuts to ISAJET Monte Carlo τ's is 0.2903 ± 0.0007. The efficiency, $\epsilon = 0.1307 \pm 0.0034$, is determined by applying the trigger requirements and the offline selection cuts to the DBMC $W \to \tau\nu$ sample. The errors are statistical. There are in addition 2.8% uncertainty in $A\epsilon$ coming from a 3% uncertainty in the energy scale and a 2.0% uncertainty from the uncertainties in the τ branching ratios [8]. From the number of events after background subtraction and the calculated value of $A\epsilon$, DØ obtains for $\sigma_W \cdot B(W \to \tau\nu\ )$

$$2.38 \pm 0.09\ (\mathit{stat.}) \pm 0.10(\mathit{syst.}) \pm 0.13,$$

where the last error comes from the uncertainty in the integrated luminosity. The results are summarized in Table 1.

From the ratio of $\sigma_W \cdot B(W \to \tau\nu)$ to $\sigma_W \cdot B(W \to e\nu)$ one can determine the ratio of the τ and the electron charged current couplings to the W boson , g_τ^W/g_e^W. The luminosity error cancels completely in the ratio of cross sections, and there is partial cancellation of systematic erros. Using a previous measurement by DØ of $\sigma_W \cdot B(W \to e\nu)$, $2.36 \pm 0.02 \pm 0.07 \pm 0.13$ [9] they find for g_τ^W/g_e^W

$$1.004 \pm 0.019\ (\mathit{stat.}) \pm 0.026\ (\mathit{syst.})$$

The above value is consistent with unity, as expectated from lepton universality.

Table 1
Summary of DØ $\sigma(W \to \tau\nu)$ measurements

Number of Events	
$W \to \tau\nu$ Data Sample	1202
QCD Background	$106 \pm 7 \pm 5$
Noisy Events	81 ± 14
$Z \to \tau\tau$ Background	32 ± 5
$W \to e\nu$ Background	3 ± 1
$A \cdot \epsilon(W \to \tau\nu)$	
$\mathrm{Br}(\tau \to \text{hadrons } +\nu)$	(64.5 ± 2) %
$A(W \to \tau\nu)$	0.290
$\epsilon(W \to \tau\nu)$	0.127
$W \to e\nu$ cut correction	1.03
$A \cdot \epsilon(W \to \tau\nu)$	0.0379
Systematic Error on $A \cdot \epsilon$	
Monte Carlo Statistics	± 0.0010
Branching ratios	± 0.0008
Energy Scale	± 0.0011
$\int \mathcal{L} dt$	
Integrated Luminosity	(16.84 ± 0.91) pb^{-1}
$\sigma \cdot Br$	
$\sigma \cdot Br(W \to \tau\nu)$	$2.38 \pm 0.09 \pm 0.10$nb
$\sigma \cdot Br(W \to e\nu)$	$2.36 \pm 0.02 \pm 0.07$nb

4. Conclusions

The CDF and DØ experiments at the FNAL Tevatron have demonstrated that it is possible to detect τ's and extract interesting physics in spite of the formidable background from QCD jets. DØ has obtained the most precise measurement of g_τ^W/g_e^W to date, see Fig. 8. CDF has the first observation of a W charge asymmetry in $W \to \tau\nu$ events consistent with that observed in $W \to e\nu$ and $W \to \mu\nu$ events. These results test $\tau - e$ universality at high Q^2 ($\approx m_W^2$). The techniques used to identify τ's are likely to prove very valuable in the upcoming high luminosity run at the Tevatron, particularly in multi-lepton final states that are expected to be the bellweather signals of physics beyond the Standard Model.

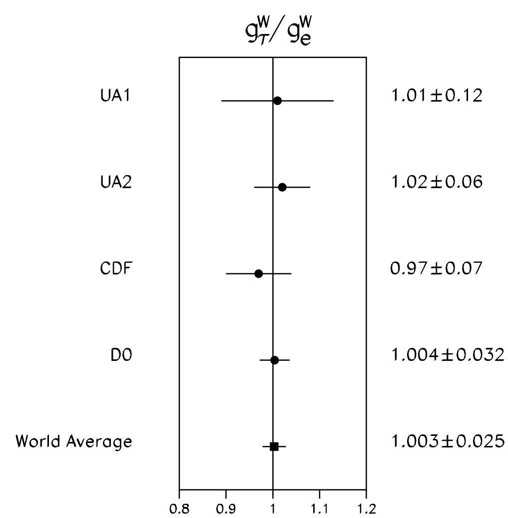

Figure 8. g_τ^W/g_e^W measurements at hadron colliders

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